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Environmental Change and the Central Great Plains, Carbon Sequestration

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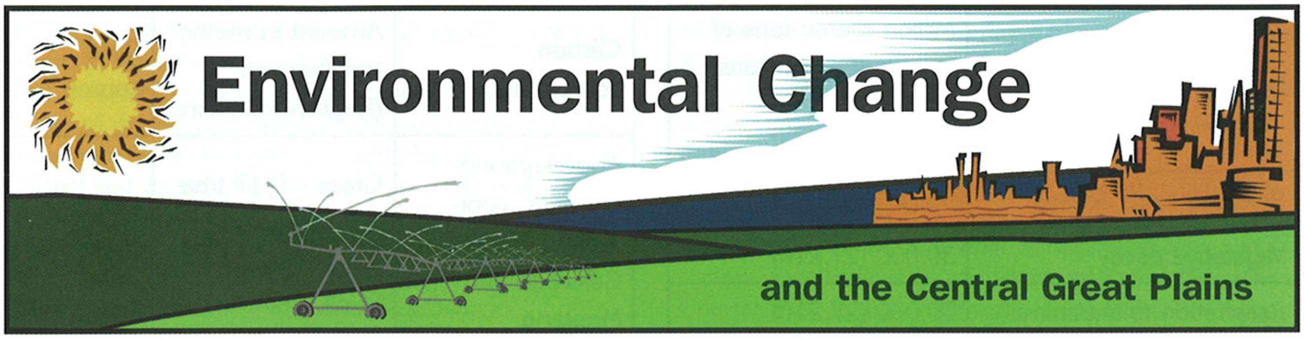

Carbon Sequestration

Compiled by Mark Mesarch, SNRS*

Introduction

Carbon dioxide (CO_2) is one of the gases associated with the greenhouse effect, which warms the planet as part of the dynamic Earth system (see Gosselin, 2001). The concentration of CO_2 in the atmosphere is rising and has shown a sharp increase since 1960 (fig. 1). Major human sources of CO_2 include burning fossil fuels to create electrical power, to heat our homes and businesses and to drive our vehicles. As CO_2 levels increase, environmental change is likely and may include increased air temperature and changes in precipitation. Reduction in emissions of CO_2 and other greenhouse gases is needed, but the projected cost of implementing reduction strategies is considered impractical at this time. With 4 percent of the world's population, the United States accounts for a quarter of the world's total CO_2 emissions. (Ruark, 2000) An alternative, although temporary, solution, would be to remove carbon dioxide from the atmosphere. This is known as *carbon sequestration* (or storage).

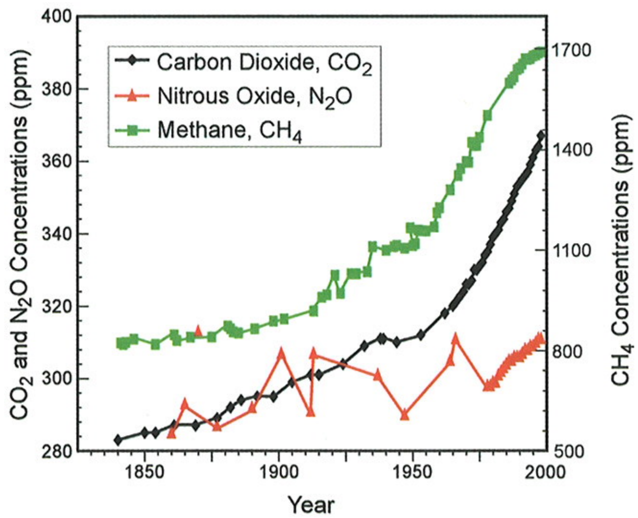

Fig. 1. Concentrations of greenhouse gases carbon dioxide, nitrous oxide and methane in the atmosphere.

Carbon is stored in many forms. Over hundreds of years, the ocean absorbs most of the CO_2 in the atmosphere. Forests and other vegetation are also major storage "sinks." Scientists are also beginning to recognize the value of soil as a sink. And there is even some research into extracting carbon from the air in a pure soluble form. This article will focus on the processes, magnitude and strengths and weakness of carbon sequestration in the soils and vegetation of the Great Plains.

How Much Carbon Was There and How Much Is There Now?

Table 1 explains that about 60,000 million metric tons of carbon are estimated to be stored in the soil and vegetation. To understand how the land-based part of the earth-carbon system functions, a baseline of carbon content in an unaltered, mostly "natural" environment is important. Researchers in North Dakota used historic soil-test data from never-tilled prairies to estimate carbon storage as a baseline for determining changes when land is placed into cultivation. They found 35.8 tons/hectare (15.99 English tons/acre) to 45.8 tons/hectare (20.45 English tons/acre) of carbon in undisturbed soils. (Cihacek, 2000).

Historical land use and vegetation types greatly determine the current carbon storage and potential cycling from these managed and natural systems. Traditional farming practices of cropping and then leaving fields fallow (not farmed), of conversion of rangeland to cropland (fig. 2) and of deforestation all release carbon back into the atmosphere. The last two practices also remove viable sinks for carbon already in the atmosphere. Agricultural practices have resulted in the loss of 25-43 percent of soil organic carbon on farmlands, compared to never-tilled prairie soils. With restoration of marginal cropland to prairie vegetation, it may take up to 100 years for soil carbon levels to return to the level of native prairie (Potter and others, 2000). This conversion also has

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Sources	Million metric tons of carbon (English tons, used in U.S., in parentheses)
Released from oceans	90,000 (81,630)
Vegetative decay	30,000 (27,210)
Respiration (plant/animal)	30,000 (27,210)
Human sources	7,100 (6,439)
Total	157,100 (142,490)
Sinks	**Million metric tons of carbon (English tons)**
Oceans	90,000 (81,630)
Terrestrial	60,000 (54,420)
Other	40,000 (36,280)
Total	154,000 (139,678)
Net Loss to Atmosphere	**3,100 (2,812)**

Table 1. Global carbon sources and sinks per year.

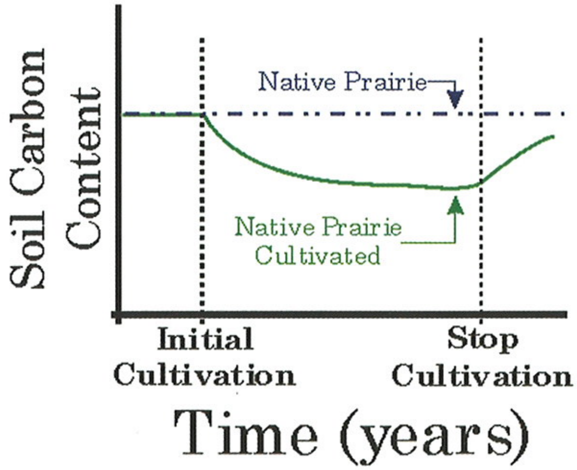

Fig. 2. Change in soil carbon content when a native prairie is cultivated and then returned to prairie compared to a permanent native prairie.

adverse effects on the nutrient supply capacity of soil (Burke and others, 1990). Conversion of forest to cropland can cause the loss of most of its woody biomass and half its soil carbon (Hass and others, 1957; Cole and others, 1990). Table 2 gives some examples of the current amount of carbon stored by different kinds of land-management systems.

Carbon source/sink	Amount in metric tons/hectare (English tons/acre)	Data source
Above-ground biomass, cool-season grasses – Colorado and Montana	Grass – 0.17 t/ha (0.076 t/ac) Soil – 16.2 t/ha (7.23 t/ac)	Haas and others, 1957; Cole and others, 1990
Above-ground biomass in shortgrass steppe – Colorado	Grass – 0.23 t/ha (0.1 t/ac) Soil – 11.6 t/ha (5.18 t/ac)	
Above-ground biomass in established shelter belts; accumulation/year	22 t/ha (9.8 t/ac) to 208 t/ha (93 t/ac); 0.5 t/ha/yr (0.22 t/ac/yr) to 27.8 t/ha/yr (12.4 t/ac/yr)	Turnock and Kort, 2000
Estimate of all above-ground biomass of corn in North America	**920 million tons**	Griffith, 1994

Table 2 . Amounts of carbon and rates of change of carbon.

Environmental Change on the Great Plains

In climate change scenarios, changes in temperature and precipitation patterns in the Great Plains will have an additional effect on carbon sequestration. Soil organic matter will continue to decline in dryland crop-management systems where little excess crop residue is present. Systems such as wheat-fallow (wheat one year and fallow the next) continue to deplete soil carbon since temperature and moisture conditions favor release of carbon by soil microorganisms during the fallow period. Systems that incorporate excess crop in the soil tend to increase soil carbon.

The environment will naturally adapt to climate change. Test plots subjected to elevated atmospheric CO_2 had greater soil-carbon concentrations than plots with current conditions, which suggests that tallgrass prairies can sequester carbon in response to rising atmospheric CO_2 (Rice, 2000). Even under traditional farming practices, soil-carbon content has increased on average by 11 percent under elevated CO_2 levels (Bunce, 2000).

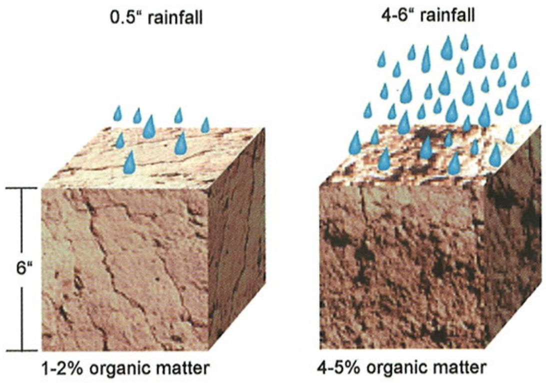

Fig. 3. Six-cubic-inch soil blocks with different amounts of soil organic matter can hold different amounts of water.

Harvesting Carbon

Some current land-management practices could be beneficial in ventures of carbon storage while providing many other environmental and cropping benefits. Some of these practices are:

- Using conservation (reduced) or no-till cultivation systems;
- Rotating crops and incorporating small grains, hay, legumes, and other crops into the rotation;
- Planting cover crops;
- Minimizing summer fallow;
- Improving pasture and rangeland soils through grazing, vegetation, and fire management;
- Installing permanent vegetative conservation buffers, such as grass waterways and filter strips;
- Converting marginal agricultural land to perennial grassland or forest;
- Adopting forestry practices that incorporate trees into agricultural operations, such as windbreaks and riparian buffers;

Some of theses practices help increase the soil organic-matter content, which improves the soil's water-holding capacity (fig. 3) and nutrient storage. Higher quality soils help crops withstand droughts, reduce soil erosion, protect water quality and minimize flooding. Currently, most farmland in the United States has half or less its historical level of organic matter.

Agricultural forestry practices, such as installing windbreaks, not only sequester carbon but can reduce stress, improve weight gain, and reduce young animal mortality in livestock operations (Quam and others, 2000). While windbreaks require some land be removed from crop production, it results in a net increase in total crop yield. On a long-term average, winter wheat yields increased 15 percent in research fields edged with windbreaks at each site at the University of Nebraska Agricultural Research and Development Center near Mead, Nebraska (fig. 4) (Brandle and Hodges, 2000). Within 20 years, field windbreaks and riparian buffers could store more than 210 million metric tons (191 million English tons) and 110 million metric tons (99.8 million English tons) of carbon, respectively (USDA, 2001). An additional advantage of incorporating windbreaks into production systems is the reduction in fossil fuel use and the resulting reduction in CO_2 emissions. Some estimates (Brandle and Schoeneberger, 2001) put these savings at levels of 2 to 3 times the levels of carbon storage. Furthermore, these reductions occur **every year** and are **permanent**.

Research into some of these areas still shows that not everything is known about various management practices, and benefits may vary from place to place. For example, young growing forests sequester carbon at much higher rates than mature forests. In older stands, carbon assimilation about equals carbon emissions from vegetation decay (Birdsey, 1992). One study found that soil organic uptake did not continue to increase after 15 year of rangeland restoration (Christiansen and Thompson, 2001). Studies have found that the rate of carbon sequestration for warm-season grasses is

Fig. 4. Shelterbelt study at the Agricultural Research and Development Center, University of Nebraska, near Mead, Nebraska. Photo courtesy of University of Nebraska-Lincoln.

slower than for cold-season grasses but the warm-season grasses are more efficient at sequestration. (Cambardella and others, 2000) Another study found that the removal of corn silage, compared to returning the residue and only removing the grain, resulted in no difference in the soil-carbon content after 30 years of continuous corn under moldboard-plow tillage (non-conservation tillage). Some studies also show that during a break from no-till farming, the soil loses most of the carbon gained in the no-till practice, so the practice must be continuous to maintain the benefits (Hill, 2001).

Help in Harvesting Carbon

Some of the management practices require a sizable capital investment or increase farm-operation costs at first. A few programs that provide assistance are the Conservation Reserve Program (CRP), Wetland Reserve Program (WRP), Stewardship Incentive Program (SIP), Forestry Incentive Program (FIP), Environmental Quality Incentive Program (EQIP), and AgSTAR (a voluntary program to encourage methane recovery technologies at confined animal feeding operations that manage manure as liquids or slurries).

Creating Win-win Carbon Sequestration Options

One thing leads to another. All Earth-system processes are connected. Storing (sequestering) carbon in the soil will increase soil organic matter. As soil organic matter increases, the soil can hold more water and allow more to infiltrate. This reduces flooding threats and erosion danger and retains moisture longer, so plants have access to the water during drought periods. Less irrigation will be needed, which reduces that expense, while also lowering the threat of groundwater and surface-water pollution from fertilizer leaching and runoff. This also reduces the amount of fertilizer needed. Another method of sequestering carbon would be to add "permanent" vegetation in windbreaks, riparian buffer zones and filter strips. Added vegetation provides habitat and reduces evaporation losses. Filter strips and riparian buffers can "catch" chemicals that would be washed away in runoff and so reduce surface-water pollution – actually, slow them so that microbes can break them down into more harmless daughter products (figs. 5a and 5b). More landowners implementing commonly used land practices on a wider scale can lead to win-win scenarios that include increased agricultural production and reduced atmospheric carbon, as well as other environmental benefits (fig. 6).

References

Birdsey, R. A., 1992, Carbon storage and accumulation in U.S. Forests, *in* Joyce, L. A. (ed.), Productivity of America's forests and climate change: U.S. Forest Service, Technical Report RM-GTR-271, Fort Collins, Colorado.

Brandle, J., and Hodges, L., 2000, Field windbreaks: University of Nebraska, Extension Educational Circular 00-1778-X.

Brandle, J., and Schoeneberger, M., 2001, Tree-buffer based technologies for sustainable land use in the central U.S.:

Figure 5a. Conversion of an unmanaged drainage area (this page) to a riparian buffer area (next page), Bear Creek, central Iowa, 1990. A stretch of Bear Creek with badly eroded banks was in need of protection. A riparian buffer strip was established as part of a research project by Iowa State University. Photo courtesy of Department of Forestry, Iowa State University.

University of Nebraska School of Natural Resource Sciences seminar, February 29, 2001.

Bunce, J.A., 2000, Increased soil carbon content after six years of doubled atmospheric carbon dioxide in a crop rotation system, *in* Carbon – exploring the benefits to farmer and society, Des Moines, Iowa: Chariton Valley Resource Conservation and Development, Centerville, Iowa, retrieved October 9, 2000, from the World Wide Web: http://www.cvrcd.org/carbon.htm. *(Home page is available; this link was not up at press time.)*

Burke, I.C., Kittel, T.G.F., Lauenroth, W. K., Snook, P., Yonker, C.M., and Parton, W.J., 1990, Regional analysis of the Central Great Plains – sensitivity to climate variability: Bioscience, v. 41, p. 685-692.

Cambardella, C. A., Marquez, C. O., Pickle, J. E., Isenhart, T. M., Schultz, R. C., Raich, J. M. and Tufekcioglu, A., 2000, Soil C storage potential in riparian buffer zones, *in* Carbon – exploring the benefits to farmer and society, Des Moines, Iowa: Chariton Valley Resource Conservation and Development, Centerville, Iowa, retrieved October 9, 2000, from the World Wide Web: http://www.cvrcd.org/carbon.htm. *(Home page is available; this link was not up at press time.)*

Cihacek, L.J., Ulmer, M.G. , Seaholm, J., and Kimble, J., 2000, Estimation of soil carbon from historical soil test data and soil survey information within MLRA56, in Carbon – exploring the benefits to farmer and society, Des Moines, Iowa: Chariton Valley Resource Conservation and Development, Centerville, Iowa, retrieved October 9, 2000 from the World Wide Web : http://www.cvrcd.org/carbon.htm. *(Home page is available; this link was not up at press time.)*

Christiansen, P.A., and Thompson, M. L., 2001, Changes in soil organic carbon following establishment of prairie species, *in* Carbon – exploring the benefits to farmer and society, Des Moines, Iowa: Chariton Valley Resource Conservation and Development, Centerville, Iowa, retrieved October 9, 2000, from the World Wide Web: http://www.cvrcd.org/carbon.htm. *(Home page is available; this link was not up at press time.)*

Cole, C. V., Burke, I.C., Parton, W. J., Oilma, D.S., and Stewart, J. W. B., 1990, Analysis of historical changes in soil fertility and organic matter levels in North America Great Plains, *in* Challenges in dryland agriculture – a global perspective: Proceedings of the International Conference on Dryland Farming, August 1988, Bushland/ Ammarillo, Texas, p. 436-438.

Griffith, B. and Bruulsema, T., 2000, Global greenhouse gases: implications for North American agriculture: Upper Midwest Aerospace Consortium, Grand Forks, North Dakota, retrieved October 9, 2000, from the World Wide Web: http://www.umac.org/Climate/Papers/ pg22-34.htm. *(Home page is available; this link was not up at press time.)*

Fig. 5b. Well-vegetated riparian buffer strips not only trap surface water pollutants such as sediment and agricultural chemicals, they help store carbon. A riparian buffer strip was established in 1990 on this stretch of Bear Creek in central Iowa as part of a research project by Iowa State University. Compare to the eroded stream bank of four years before in the previous figure (5a). Photo courtesy of Department of Forestry, Iowa State University.

Griffith W. K., 1994, Facts and scientific evidence – the basis for a fertilizer use policy in the United States: Potash and Phosphate Institute, Item No. 120-0009, Reference No. 94056, Norcross, Georgia.

Gosselin, D.C., 2001, Environmental change and the Great Plains – past, present and future: University of Nebraska-Lincoln, Conservation and Survey Division, Earth Science Notes No. 2.

Haas, H. J., Evans, C. E., and Miles, E.F., 1957, Nitrogen and carbon changes in Great Plains soils influenced by cropping and soil treatments: U.S. Department of Agriculture, Technical Bulletin 1164.

Hill, P.R., 2001, Continuous use of no-till cropping systems in the corn belt, *in* Carbon – exploring the benefits to farmer and society, Des Moines, Iowa: Chariton Valley Resource Conservation and Development, Centerville, Iowa, retrieved October 9, 2000, from the World Wide Web: http://www.cvrcd.org/carbon.htm. *(Home page is available; this link was not up at press time.)*

Potter, K.N., Torbert, H.A., and Daniel, J.A., 2000, Carbon storage in degraded farmlands converted to grass – effects of time and grazing, *in* Carbon – exploring the benefits to farmer and society, Des Moines, Iowa: Chariton Valley Resource Conservation and Development, Centerville, Iowa, retrieved October 9, 2000, from the World Wide Web: http://www.cvrcd.org/carbon.htm. *(Home page is available; this link was not up at press time.)*

Quam, V.C., Gardner, J., Brandle, J.R., and Boes, T. K., 2000, Windbreaks in sustainable Agricultural systems: University of Nebraska, Cooperative Extension Educational Circular 91-1772-X.

Rice, C.W., Owensby, C.E., Williams, M., and Espinoza, Y., 2000, Sequestration of carbon dioxide into grassland soils under elevated CO_2, *in* Carbon – exploring the benefits to farmer and society, Des Moines, Iowa: Chariton Valley Resource Conservation and Development, Centerville, Iowa, retrieved October 9, 2000, from the World Wide Web: http://www.cvrcd.org/carbon.htm. *(Home page is available; this link was not up at press time.)*

Ruark, G., 2000, The carbon debate – a primer, *in* Inside Agroforestry: USDA National Agropforestry Center, fall/winter 2000/2001.

Turnock, R., and Kort, J., 2000, The carbon sequestration potential of prairie shelterbelts and their possible role in a national greenhouse gas mitigation strategy, in Carbon – exploring the benefits to farmer and society, Des Moines, Iowa: Chariton Valley Resource Conservation and Development, Centerville, Iowa, retrieved October 9, 2000, from the World Wide Web: http://www.cvrcd.org/carbon.htm. *(Home page is available; this link was not up at press time.)*

U.S. Department of Agriculture, Soil and Water Conservation Society, Environmental Defense, 2000, Growing carbon – a new crop that helps agricultural produces and the climate too: Soil and Water Conservation Society, hard copy and from the World Wide Web, retrieved October 9, 2000: http://www.swcs.org/.

U.S. Department of Agriculture National Agroforestry Center, 2001, Working trees for carbon: Windbreaks in the U.S., brochure and, retrieved July 23, 2001, from the World Wide Web: http://www.unl.edu/nac/brochures/wbcarbon/index.html.

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Fig. 6. A multifaceted ecosystem of agricultural crops, windbreaks and riparian buffer areas benefits each component separately and the whole system collectively, as well as sequestering atmospheric carbon. Photo courtesy of USDA Natural Resources Conservation Service.